

1 APPARATUS FOR TREATING METAL-WORKING FLUID

2 Applicants: Anthony H. Gonzalez, Michael Birran, and Michel Jammal

3 RELATED APPLICATIONS

4 **[0001]** This application is a divisional application of prior-filed co-pending App. No.
5 09/812,480 entitled "Methods and apparatus for treating metal-working fluid" filed
6 03/19/2001 in the names of Anthony H. Gonzalez, Michael Birran, and Michel Jammal,
7 with in turn claims benefit of provisional App. No. 60/190,761 entitled "Methods and
8 apparatus for treating metal-working fluid" filed 03/20/2000 in the names of Anthony H.
9 Gonzalez, Michael Birran, and Michel Jammal. Both of said applications are hereby
10 incorporated by reference as if fully set forth herein.

BACKGROUND

[0002] The field of the present invention relates to handling of metal-working fluid. In particular, methods and apparatus are described herein for treating metal-working fluid for re-use.

[0003] Currently-used aqueous metal-working fluid formulations contain agents such as biocides, extreme pressure additives, antioxidants, corrosion inhibitors, dyes, water conditioners, and so forth. These agents may comprise formaldehyde, ethanolamines, chlorinated compounds, detergents, nitrites, nitrates, phosphates, borates, and other organic and/or inorganic compounds. Furthermore, aqueous metal-working fluids are prone to microbial contamination and for this reason often contain biocides.

Recognized diseases associated with metal-working fluid include contact dermatitis, work-related asthma, and hypersensitivity pneumonitis. It is evident that many metal-working fluid agents as well as microbial contaminants are harmful to metal workers and the environment.

[0004] Long term debilitating conditions due to contact with contaminated metal-working fluid and increased burden on the environment demand effective management methods. However, management of metal-working fluid is technically difficult and expensive. Machining operations employ elaborate enclosures to control the dispersal of metal-working fluid mists. Contaminated metal-working fluid must be evaporated and/or transported to dump sites by certified agents. Management of contaminated metal-working fluid by disposal results in its accumulation in landfills and dump sites. More importantly, worker health issues cannot be ignored. There are over two million metal workers in the United States alone, and the industry is growing and with that growth arises the potential to expose even more workers to metal-working fluid exposure hazards.

[0005] Tool grinders and saw fillers using carbide or stellite tipped tools may develop asthma or hard metal lung disease. These health-debilitating conditions are currently viewed as a result of exposure to cobalt, although other transition and/or heavy metals may also be implicated. Two principal features of hard metal lung disease are inflamed and scarred alveolar tissue. Treatment of these conditions includes medication and

1 perhaps removal from the work place. However, not all patients may respond to
2 treatment. There are other diseases reported to be associated with cobalt exposure.
3 Some of the reported diseases are contact dermatitis, eczema, cardiomyopathy and
4 lung cancer. Whether these medical conditions arise through exposure to metal
5 particulates or exposure to aqueous solutions containing metal ions (liquid or mist) has
6 not been elucidated.

7 **[0006]** Biocides have been used for years in an attempt to control microbial
8 contamination in metal-working fluid as well as other fluids. The addition of such
9 biocides represents an added expense, and is also difficult to control. Some studies
10 show that they are effective for only a brief period of time and never completely inhibit
11 bacteria and other microbes. Furthermore, biocides may induce selection in
12 mycobacteria, recently associated with hypersensitivity pneumonitis, and other
13 microbes, thereby producing resistant strains of these micro-organisms. Byproducts of
14 microbial contamination may also pose health risks to and/or create an unpleasant work
15 environment for metal workers. In particular, significant microbial contamination is often
16 also accompanied by production of hydrogen sulfide, a malodorous and potentially
17 harmful contaminant.

18 **[0007]** The Safe Drinking Water Act requires disinfection of all public water supplies. It
19 further requires the Environmental Protection Agency (EPA) to set standards and
20 establish processes for the treatment and distribution of disinfected water. The Act
21 ensures that no significant risks to human health arise from public water supplies.
22 Disinfectants and filtration systems are currently acceptable methods for treating water
23 supplies. However, EPA has evidence linking disinfectant byproducts to cancers and
24 other toxic effects.

25 **[0008]** EPA actively seeks innovative technology to upgrade existing methods. These
26 new technologies may include alternatives to chlorine, innovative applications of UV
27 irradiation, and other processes that improve methods of treating public water supplies.
28 The agency's goals are to develop new methods that remove organic and inorganic
29 compounds as well as particulate matter and pathogens. The organic and inorganic
30 compounds of particular interest may include perchlorates, aluminum, pesticides,

- 1 arsenic, nitrates, and radium. Pathogens of particular interest may include
- 2 cryptosporidium, caliciviruses, microsporidia, echoviruses, and adenoviruses.
- 3 **[0009]** It is therefore desirable to provide apparatus and methods for treating metal-
- 4 working fluid that addresses the problems associated with contaminated metal-working
- 5 fluid, exposure thereto, and disposal thereof.

1 SUMMARY

2 **[0010]** Certain aspects of the present invention may overcome one or more
3 aforementioned drawbacks of the previous art and/or advance the state-of-the-art of
4 treatment of metal-working fluid, and in addition may meet one or more of the following
5 objects:

6 **[0011]** To provide apparatus and methods for treating metal-working fluid whereby the
7 useful life of the metal-working fluid is extended;

8 **[0012]** To provide apparatus and methods for treating metal-working fluid wherein the
9 likelihood of metal-working fluid exposure-related illness in metal workers is
10 reduced;

11 **[0013]** To provide apparatus and methods for treating metal-working fluid wherein
12 particulates are filtered from the metal-working fluid;

13 **[0014]** To provide apparatus and methods for treating metal-working fluid wherein
14 microbial contamination may be suppressed and/or eliminated without using
15 biocides;

16 **[0015]** To provide apparatus and methods for treating metal-working fluid wherein
17 microbial contamination may be suppressed and/or eliminated by heating the
18 metal-working fluid;

19 **[0016]** To provide apparatus and methods for treating metal-working fluid wherein the
20 metal-working fluid is agitated and/or aerated during treatment;

21 **[0017]** To provide apparatus and methods for treating metal-working fluid wherein
22 gaseous and/or malodorous contaminants are removed by aeration and/or
23 filtration;

24 **[0018]** To provide apparatus and methods for treating metal-working fluid wherein
25 concentrations of cobalt and/or other metal ions are reduced by treatment of the
26 metal-working fluid;

1 **[0019]** To provide apparatus and methods for treating metal-working fluid wherein
2 concentrations of cobalt and/or other metal ions are reduced by passing the
3 metal-working fluid through an ion-exchange medium;

4 **[0020]** To provide apparatus and methods for treating metal-working fluid wherein
5 metal-working machine down time due to metal-working fluid treatment is
6 reduced or substantially eliminated; and

7 **[0021]** To provide apparatus and methods for treating metal-working fluid that may be
8 readily and/or economically implemented in a typical metal-working work
9 environment.

10 **[0022]** One or more of the foregoing objects may be achieved in the present invention
11 by a method for treating metal-working fluid comprising the steps of: a) transferring the
12 metal-working fluid into a heating vessel; b) heating the metal-working fluid in the
13 heating vessel to maintain the metal-working fluid at an elevated temperature during a
14 heating period; c) agitating and aerating the metal-working fluid during the heating
15 period; d) transferring the metal-working fluid out of the heating vessel into a holding
16 vessel after the heating period; and e) transferring the metal-working fluid out of the
17 holding vessel. The fluid may pass through a particle filter before entering the heating
18 vessel, and it may be heated to between about 145° F and about 210° F for at least
19 about 30 minutes while in the heating vessel. During heating, heated ambient air may
20 be drawn through air inlets and through the metal-working fluid to agitate and aerate the
21 metal-working fluid, thereby ensuring substantially uniform heating and extracting
22 gaseous contaminants. Mist and gaseous contaminants are substantially removed from
23 the airflow prior to its release into the surroundings. After the heating period the treated
24 metal-working fluid is transferred into a holding vessel and ultimately back to a metal-
25 working machine for re-use. The metal-working fluid may flow through an ion-exchange
26 medium to reduce concentrations of cobalt and/or other metal ions before transfer of the
27 fluid back to a metal-working machine.

28 **[0023]** One or more of the foregoing objects may be achieved in the present invention
29 by an apparatus for treating metal-working fluid, the apparatus comprising: a) a heating
30 vessel; b) a heater for heating the metal-working fluid in the heating vessel to an

1 elevated temperature to maintain the metal-working fluid at the elevated temperature
2 during a heating period; c) an agitator for agitating the metal-working fluid during the
3 heating period; d) an aerator for aerating the metal-working fluid during the heating
4 period; e) a holding vessel; and f) a pump for transferring the metal-working fluid from
5 the heating vessel into the holding vessel after the heating period. The apparatus may
6 further include a particulate filter through which the metal-working fluid may flow before
7 and/or during transfer into the heating vessel, and an ion-exchange medium through
8 which the metal-working fluid may flow before and/or during transfer back to a metal-
9 working machine.

10 **[0024]** Additional objects and advantages of the present invention may become
11 apparent upon referring to the preferred and alternative embodiments of the present
12 invention as illustrated in the drawings and described in the following written description
13 and/or claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] Figure 1 schematically illustrates methods and apparatus for treating metal-working fluid according to the present invention.

[0026] Figure 2 schematically illustrates methods and apparatus for treating metal-working fluid according to the present invention.

[0027] Figure 3 schematically illustrates methods and apparatus for treating metal-working fluid according to the present invention.

[0028] Figure 4 schematically illustrates methods and apparatus for treating metal-working fluid according to the present invention.

[0029] Figure 5 schematically illustrates methods and apparatus for treating metal-working fluid according to the present invention.

[0030] Figure 6 schematically illustrates methods and apparatus for treating metal-working fluid according to the present invention.

[0031] Figure 7 shows a cross-section of a heating vessel and aerator/agitator according to the present invention.

[0032] Figure 8 shows a cross-section of an ion-exchange filter according to the present invention.

[0033] In the Figures, fluid/liquid flow is designated by solid arrows, while air/gas flow is designated by open arrows. A bow-tie-shaped valve symbol with a transverse line segment is closed, while a valve symbol without a transverse line segment is open.

DETAILED DESCRIPTION OF PREFERRED AND ALTERNATIVE EMBODIMENTS

[0034] Figures 1 through 6 illustrate schematically methods and apparatus for treating metal-working fluid according to the present invention. The apparatus comprises a heating vessel 100, a holding vessel 200, a heater for heating the metal-working fluid in heating vessel 100, and agitator for agitating the metal-working fluid in heating vessel 100, an aerator for aerating the metal-working fluid in heating vessel 100, and a pump for transferring the metal-working fluid out of the heating vessel 100 and into the holding vessel 200. For purposes of the present written description and claims, the term "pump" shall broadly designate any device used to induce a flow of material (fluid, liquid, air, gas, and so forth) through generation of a pressure differential/gradient between a flow source and a flow destination. Heating vessel 100 and holding vessel 200 may be fabricated from any material compatible with the metal-working fluid to be treated and able to tolerate the elevated temperatures needed for treatment of the metal-working fluid, including but not limited to metals, plastics, other polymeric resins, and the like. A preferred material for heating vessel 100 and holding vessel 200 is stainless steel. In a typical machine shop environment volumes of about 5 gallons to about 50 gallons of metal-working fluid may require treatment, and the heating and holding vessels may be suitably large to accommodate these volumes, although the vessels may be sized to treat any desired volume of metal-working fluid.

[0035] Used metal-working fluid in need of treatment according to the present invention preferably may be drawn into heating vessel 100 (as shown in Figure 1) by opening valves B, E, and E', while closing valves C, K, and T. Open valve E' provides shop compressed air from compressed air supply line 30 to drive air flow amplifier 9, thereby applying negative air pressure (between about 1 psi and about 7 psi, preferably about 3 psi, below ambient atmospheric pressure) to heating vessel 100 through open valve E and drawing the metal-working fluid from a sump or reservoir of a metal-working machine through transfer line 20, through filter 5 and open valve B, and into heating vessel 100. Filter 5 may be any suitable filter for removing particulates and debris from the metal-working fluid prior to treatment. A bag filter (polymeric mesh/weave, 10-250 μm particle size) may be preferred, but a variety of suitable filters may be employed

1 without departing from inventive concepts disclosed and/or claimed herein, including but
2 not limited to bag filters, rope/string filters, mesh or screen filters (metal, plastic,
3 polymeric, fiber, or other, paper filters, and the like). The filtered metal-working fluid is
4 drawn in heating vessel 100 until the transfer is stopped manually or until full, which
5 may be indicated by an upper fluid level limit switch 7 or other suitable fluid level sensor.
6 Alternatively, air flow amplifier 9 may be provided with a safety valve for preventing
7 entry of metal-working fluid thereinto, thereby stopping inflow of metal-working fluid into
8 heating vessel 100 when the level of air flow amplifier 9 is reached. After transfer of the
9 metal-working fluid 150 into heating vessel 100, valves B, E, and E' are closed.

10 **[0036]** Air flow amplifier 9 may comprise a compressed-air-driven device as disclosed
11 in U.S. Patent No. 4,046,492, said patent being hereby incorporated by reference as if
12 fully set forth herein. Use of such a source for applying negative air pressure to heating
13 vessel 100 is particularly well-suited to the present invention. A typical use environment
14 for the present invention is a machine shop where compressed air is often readily
15 available. Without departing from inventive concepts disclosed and/or claimed herein,
16 any other source of negative pressure, suction, and/or vacuum may be equivalently
17 employed (in place of air flow amplifier 9 and/or any other air flow amplifier disclosed
18 herein). Without departing from inventive concepts disclosed and/or claimed herein,
19 any of a variety of alternative methods may be employed for transferring metal-working
20 fluid into heating vessel 100, including but not limited to: drawing fluid into the heating
21 vessel by applying negative air pressure to the heating vessel; driving fluid into the
22 heating vessel by applying positive air pressure to the fluid; using a fluid pump to
23 transfer the fluid; siphoning the fluid into the heating vessel; collecting and transferring
24 the fluid in a transfer vessel (i.e., a bucket) and pouring it into the heating vessel;
25 combinations thereof; functional equivalents thereof. Heating vessel 100 may be
26 provided with safety pressure relief valve 110 for venting excessive air and/or fluid
27 pressure within heating vessel 100. Relief valve 110 may be set to open at about 5 psi
28 to about 15 psi above ambient atmospheric pressure. A plurality of safety valves
29 covering a range of opening pressures may be employed to add a degree of
30 redundancy in case of safety valve failure.

1 **[0037]** Once the metal-working fluid 150 has been transferred into heating vessel 100,
2 the heating cycle may begin (Figure 2). Valves A, D, G, G', K, J, M, and U are opened,
3 while valves B, C, E, E', and T are closed. Centrifuge impactor 6 is activated, as is a
4 recirculating heater 120 for circulating heating fluid through heat exchanger P within
5 heating vessel 100. Valve D may be provided for servicing the heater and/or heat
6 exchanger, is typically manually operated, and is typically left in an open position.
7 Safety valve 2 may provided to prevent over-pressuring of the recirculation system for
8 the heater. Pump 3 drives recirculation of heating fluid through heater 120 and heat
9 exchanger P and may preferably comprise a seal-less chemical pump driven by shop
10 compressed air via open valve U, although any suitable fluid pump may be employed.
11 Heat exchanger P typically comprises one or more finned heating tubes positioned
12 within heating vessel 100. The fins may comprise a series of transverse disks or plates
13 connected to and extending radially outward from the tube, thereby increasing the
14 surface area of contact between the heat exchanger P and the metal-working fluid to be
15 heated. The tube may be substantially vertically oriented within heating vessel and may
16 be provided with one or more coils and/or S-turns, and the recirculating heating fluid
17 may preferably flow from the top of heating vessel 100 to the bottom. Any other suitable
18 geometry for the heat exchanger (including tube and fins) may be equivalently
19 employed without departing from inventive concepts disclosed and/or claimed herein.
20 The tube and fins are preferably fabricated from suitably thermally conductive material,
21 preferably metal, most preferably copper, stainless steel, and/or aluminum. The
22 recirculating heating fluid may comprise water, ethylene glycol, a suitable
23 water/ethylene glycol mixture, any of a variety of oils or other organic fluids (alcohols,
24 glycols, hydrocarbons, and so forth), steam, air, inert gases, other gases, combinations
25 thereof, and/or functional equivalents thereof. Without departing from inventive
26 concepts disclosed and/or claimed herein, any suitable means may be employed for
27 heating metal-working fluid in the heating vessel 100. These may include but are not
28 limited to: the recirculating heater and heating exchanger as described hereinabove; a
29 recirculating heater for heating the walls of heating vessel 100; resistive electrical
30 heating elements within heating vessel 100 and/or on the walls of heating vessel 100;
31 flame and/or forced air heating of the exterior of heating vessel 100; steam injection

1 directly into the metal-working fluid; combinations thereof; and/or functional equivalents
2 thereof. Heating vessel 100 may be provided with insulation to improve the efficiency of
3 the heating process.

4 **[0038]** The metal-working fluid 150 is heated in heating vessel 100 to an elevated
5 temperature and maintained at about that temperature during a heating period (defined
6 as the time period during which the metal-working fluid is maintained at about the
7 desired elevated temperature, but not including time required to reach the elevated
8 temperature). Most metal-working fluid formulations (with the exception of straight oils)
9 may typically contain 10⁵-10⁶ microbial colony-forming units (CFUs) per milliliter, and
10 used metal-working fluid may contain upwards of 10⁸-10⁹ CFU/ml. Biocides may
11 reduce microbe levels to about 10⁴ CFU/ml. It has been observed that treating used
12 metal-working fluid according to the present invention by heating the metal-working fluid
13 to a preferred elevated temperature of about 160° F for a preferred heating period of
14 about one hour reduces microbe levels to less than about 10² CFUs. If less complete
15 killing of microbes is tolerable, the elevated temperature may be reduced to about 145°
16 F, and the heating period may be as short as about 30 minutes. Still lower elevated
17 temperatures and/or shorter heating periods may be suitable depending on the
18 particular situation. Longer heating periods and/or higher elevated temperatures may
19 be required for more complete killing of micro-organisms, or for killing of more
20 hardy/resistant forms of micro-organisms. In any case, the elevated temperature should
21 preferably be kept below the boiling point of the metal-working fluid (less than about
22 210° F) and below a cracking temperature of any components of the metal-working
23 fluid. Multiple heating periods, with intervening non-heated periods, may be employed
24 for enhanced killing/suppressing of spore-forming microbes.

25 **[0039]** It is desirable to agitate and aerate the metal-working fluid 150 during
26 treatment. Aeration is desirable for killing and/or suppressing anaerobic micro-
27 organisms in the metal-working fluid, and is helpful for removing hydrogen sulfide and
28 other gaseous (and possibly malodorous and/or toxic) contaminants from the metal-
29 working fluid. Agitation is desirable to insure substantially uniform heating of the entire
30 volume of the metal-working fluid, and to mechanically break up so-called "biofilms"
31 and/or other microscopic and/or macroscopic aggregations of micro-organisms. Both

1 aeration and agitation of the metal-working fluid during the heating period may be
2 preferably implemented in the present invention by bubbling heated ambient air through
3 the metal-working fluid as it is heated. The bottom of the heating vessel 100 is provided
4 with a plurality of air inlets N, through which ambient air enters through open valve A and
5 heating coils 4. Heating coils 4 may be heated by heater 120 (also used to heat the
6 metal-working fluid preferably via recirculating heating fluid) or may be provided with an
7 independent, dedicated heating element of any suitable type. Preheating the incoming
8 air flow in this way reduces any cooling of the metal-working fluid by the incoming air
9 flow as the metal-working fluid is being heated. As shown in the cross-section of Figure
10 7, the air inlets are preferably arranged roughly along a line near the center of heating
11 tank 100. The upward flow of air bubbles from inlets N as air flows through the metal-
12 working fluid 150 causes the fluid to flow upward above the inlets. A counter-balancing
13 downward fluid flow develops near the two sides of the heating vessel. These two
14 counter-rotating flows, or eddies, serve to agitate the metal-working fluid as it is being
15 heated, thereby insuring substantially uniform heating of the metal-working fluid. These
16 eddies also serve to mechanically break up microscopic and macroscopic aggregates of
17 micro-organisms, thereby facilitating killing and/or suppressing them. Heating vessel
18 100 may preferably comprise a substantially cylindrical vessel with a substantially
19 horizontal axis and with air inlets N arranged roughly along a line at the bottom of the
20 vessel and roughly parallel to the axis of the cylinder. Other suitable vessel geometries
21 and/or inlet positions may be equivalently employed without departing from inventive
22 concepts disclosed and/or claimed herein. The geometry and fins of heat exchanger P
23 may also serve to break up aggregates and/or biofilms as the metal-working fluid and
24 air flow around and/or through them. In an alternative embodiment of the present
25 invention and without departing from inventive concepts disclosed and/or claimed
26 herein, any suitable means may be employed for agitating the metal-working fluid during
27 the heating period, including but not limited to: bubbling air or other gas through the
28 metal-working fluid, mechanically stirring the metal-working fluid, shaking the heating
29 vessel, sonication, and so forth. It should be noted that while in a preferred
30 embodiment of the present invention aeration and agitation are provided by the same
31 components and/or method steps, separate components and/or methods steps may be

1 equivalently employed to implement agitation and aeration while remaining within the
2 scope of inventive concepts disclosed and/or claimed herein.

3 **[0040]** Negative pressure (between about 1 psi and about 7 psi, preferably about 3 psi,
4 relative to the ambient atmospheric pressure) may be applied to the air volume above
5 the metal-working fluid in heating vessel 100 through open valve K to draw ambient air
6 through inlets N and through the metal-working fluid. The air flow through the heated
7 metal-working fluid serves to aerate the metal-working fluid, thus killing and/or
8 suppressing anaerobic microbes in the metal-working fluid. The air flow also serves to
9 extract hydrogen sulfide and/or other undesirable dissolved gaseous contaminants from
10 the metal-working fluid, and these contaminants flow out of heating vessel 100 through
11 valve K with the air flow. The negative pressure applied to the air volume above the
12 metal-working fluid may serve to reduce and/or substantially eliminate foaming of the
13 metal-working fluid as the air flow bubbles through it, since the bubbles will tend to burst
14 at the surface due to the reduced pressure.

15 **[0041]** The air flow leaving the heating vessel is typically laden with droplets and/or
16 mist, which is preferably removed by a de-mister comprising centrifuge impactor 6.
17 Impactor 6 may typically comprise a drum-like housing enclosing a rotary member
18 having a plurality of radially-projecting vanes thereon. The rotary member is spun at a
19 relatively high angular velocity so that the linear velocity of the vanes is on the order of a
20 hundred feet/sec or more. Droplets or mist that impact these vanes condense thereon,
21 and are then spun off to the inner surface of the housing where the resulting liquid is
22 collected for return to heating vessel 100. In an alternative embodiments of the present
23 invention and without departing from inventive concepts disclosed and/or claimed
24 herein, any suitable means may be equivalently employed for removing mist and/or
25 droplets from the airflow, including but not limited to filters, scrubbers, condensers, and
26 so forth. The de-misted air flow preferably flows through a filter 11 for removal of
27 hydrogen sulfide and/or other gaseous contaminants. Filter 11 may preferably comprise
28 an activated charcoal filter, although any suitable filter or combination of filters may be
29 employed (depending on the gaseous contaminants to be removed from the air flow)
30 without departing from inventive concepts disclosed and/or claimed herein. Examples
31 may include but are not limited to: paper and/or fiber filters, activated charcoal, zeolites,

1 catalytic filters, resins, exchange columns, chromatographic columns, impregnated
2 and/or treated filters, and so forth. As shown in Figure 2, the air flow passing through
3 filter 11 is drawn through open valve M, holding vessel 200, and open valve G, and
4 vented to the surroundings by air flow amplifier 12, driven by shop compressed air
5 through open valve G'. The de-misted and filtered airflow may equivalently be vented
6 directly from filter 11 into the surroundings. The negative pressure generated by air flow
7 amplifier 12 serves to pull the air flow through filter 11, and may also provide the
8 negative pressure applied to the air volume above the metal-working fluid in the heating
9 vessel 100. Centrifuge impactor 6 may also be configured (by suitable positioning and
10 orientation of the vanes thereof) so as to generate the negative pressure applied to the
11 air volume above the metal-working fluid and to drive the airflow through filter 11. Any
12 suitable means for producing the air flow may be employed without departing from
13 inventive concepts disclosed and/or claimed herein, including but not limited to: any
14 suitable means for applying negative pressure to the air volume above the metal-
15 working fluid; any suitable means for applying positive pressure to air inlets N, thereby
16 driving air flow through the inlets N, the metal-working fluid, the de-mister, and the filter;
17 combinations thereof; and/or functional equivalents thereof.

18 **[0042]** In a preferred embodiment of the present invention, the collected droplets
19 and/or mist from centrifuge impactor 6 flow through open valve J into reservoir 14. The
20 reservoir is periodically drained and the collected metal-working fluid returned to the
21 heating vessel by closing valve J and opening valves T and H, as shown in Figure 3.
22 Open valve H allows regulated shop compressed air (regulated to between about 1 psi
23 and about 7 psi, preferably about 3 psi, above ambient atmospheric pressure) from
24 regulator 10 to flow into reservoir 14 and drive the collected metal-working fluid through
25 open valve T and back into heating vessel 100. After a suitable time interval for
26 allowing reservoir 14 to substantially empty, valves T and H are closed and valve J re-
27 opens. This cycle repeats periodically during the heating period. Without departing
28 from inventive concepts disclosed and or claimed herein, any suitable arrangement of
29 reservoir, valves, and/or pumping means may be employed for returning fluid removed
30 from the air flow to the heating vessel. In an alternative embodiment of the present

1 invention, this collected fluid may not be returned to the heating vessel, but instead may
2 be returned to the metal-working machine or otherwise disposed of.

3 **[0043]** After the desired heating period has been completed, the metal-working fluid
4 150 is transferred into holding vessel 200, as shown in Figure 4. Valves B, E, and E'
5 remain closed, valves U, A, J, K, and M close, valves T, H, and C open, and valves G
6 and G' remain open. Metal-working fluid may flow from heating vessel 100 through
7 open valve C and into holding vessel 200. The connections to the heating and holding
8 tanks may preferably be located near the bottoms of each, thereby allowing gravity to
9 assist the transfer of metal-working fluid in the initial stages. Positive pressure supplied
10 by regulator 10 through open valves H and T assists the flow of metal-working fluid 150
11 out of heating vessel 100, while negative pressure applied by air flow amplifier 12
12 through open valve G (by compressed air supplied via open valve G') assists in drawing
13 the metal-working fluid 150 into the holding tank. The transfer continues until a low-
14 level limit switch 8 (or other suitable fluid level sensor) is tripped, or until the transfer is
15 otherwise terminated (manually, by emptying the heating vessel, by filling the holding
16 vessel, by tripping an upper fluid level limit switch or other level sensor in the holding
17 vessel, or otherwise). Without departing from inventive concepts disclosed and/or
18 claimed herein, any other suitable fluid transfer device may be employed for transferring
19 the metal-working fluid from the heating vessel to the holding vessel. These may
20 include but are not limited to: alternative devices for applying positive and/or negative
21 air pressure to the vessels; a fluid pump of any suitable type for directly pumping the
22 fluid from one vessel to the other; combinations thereof; functional equivalents thereof.
23 The transfer may even be made manually, although this may prove hazardous with the
24 metal-working fluid at an elevated temperature.

25 **[0044]** Once the transfer of metal-working fluid has terminated, valves C, G, G', H, and
26 T close and valve F opens (Figure 5), and the heated metal-working fluid is permitted to
27 cool in holding vessel 200, preferably to near ambient temperature. Holding vessel 200
28 may be provided with safety pressure relief valve 210 in a manner analogous to relief
29 valve 110 of heating vessel 100. The metal-working fluid may be allowed to passively
30 cool, or in a preferred embodiment of the present invention, a heat exchanger R may be
31 provided as a cooling element for holding tank 200 in a manner quite analogous to the

1 heat exchanger provided for heating vessel 100. A preferred heat exchanger R
2 comprises one or more fin tubes through which may flow a coolant, although many
3 other suitable configurations for the heat exchanger may be equivalently employed
4 without departing from inventive concepts disclosed and/or claimed herein. A preferred
5 coolant is cold air provided by flow of shop compressed air through open valve F and
6 through vortex tube 13. After passing through heat exchanger R the cold air may be
7 vented to the surroundings. Vortex tubes are well-known sources of cold air and are
8 disclosed in U.S. Patent Nos. 1,952,281, 3,173,273, 3,208,229, 4,240,261, and
9 4,339,926. Each of these five patents is hereby incorporated by reference as if fully set
10 forth herein. Without departing from inventive concepts disclosed and/or claimed
11 herein, any suitable coolant or refrigerant, and any suitable means for cooling the same,
12 may be employed without departing from inventive concepts disclosed and/or claimed
13 herein. Examples include but are not limited to: use of a recirculating chiller employing
14 a liquid chilling fluid; flow of cold tap water through the heat exchanger; a compressor-
15 based refrigeration device; cryogenic coolants; freon-based and/or similar refrigerants;
16 combinations thereof; and/or functional equivalents thereof. The heat exchanger is
17 preferably positioned within holding vessel 200, but may equivalently be provided on the
18 exterior thereof. Alternatively, other methods for heat removal may be employed, such
19 as thermo-electric cooling, or addition of cooling substances (ice, dry ice, or liquid
20 nitrogen, for example) directly to the metal-working fluid.

21 **[0045]** Once the metal-working fluid has reached a suitably low temperature
22 (preferably near ambient temperature) it may be transferred to the sump or reservoir of
23 a metal-working machine as shown in Figure 6. Valve F closes, and valves L and S
24 open. Positive air pressure supplied by regulator 10 flows through open valve L into
25 holding tank 200 and assists the flow of cooled metal-working fluid 150 out of holding
26 vessel 200 through open valve S and transfer line 20. The transfer continues until
27 terminated by closing valve S and/or valve L, either manually or otherwise (tripping a
28 low fluid level limit switch 8' or other level sensor in the holding vessel, emptying the
29 holding vessel, tripping an upper fluid level limit switch or other level sensor in the
30 metal-working machine, filling the metal-working machine, and so forth). Without
31 departing from inventive concepts disclosed and/or claimed herein, any other suitable

1 fluid transfer means may be employed for transferring the metal-working fluid out of the
2 holding vessel. These may include but are not limited to: alternative devices for
3 applying positive air pressure to the holding vessel; a fluid pump of any suitable type for
4 directly pumping the fluid out of the holding vessel; simple gravitational draining through
5 a drain port; manual transfer; combinations thereof; functional equivalents thereof.

6 While the entrance of metal-working fluid into the heating tank 100 and exit from holding
7 vessel 200 are shown in the Figures flowing through the same transfer line 20, separate
8 lines or passages may equivalently be employed without departing from inventive
9 concepts disclosed and/or claimed herein.

10 **[0046]** The apparatus may further include an ion-exchange filter as shown in Fig. 8.
11 Metal-working fluid may be pumped from a reservoir into filter housing 300 using fluid
12 pump 310. In a preferred embodiment, the metal-working fluid enters housing 300 and
13 flows down through ion-exchange resin 340. Central tube 320 is provided with one or
14 more openings 322 at its lower end for allowing flow of metal-working fluid therethrough.
15 Fluid flows into tube 320 through openings 322, up through central tube 320, out of
16 filter housing 300, and back into the reservoir. The upper and lower portions of the
17 interior of filter housing 300 may be filled with an inert porous packing 332 and 330,
18 respectively. The upper and lower inert packings serve to hold the ion exchange resin
19 within the filter housing and prevent clogging/fouling of tube 320, openings 322, the
20 pump, or other plumbing components connected to the filter. Alternative filter
21 configurations may employed while remaining within the scope of inventive concepts
22 disclosed and/or claimed herein. For example, in the filter of Figure 8 the fluid may flow
23 down through the central tube and up through the resin. In another example an in-line
24 or column filter geometry may be employed wherein fluid enters one end of the housing
25 and exits the other, without a central tube. The metal-working fluid may be continuously
26 recirculated through the ion-exchange filter to achieve a desired reduction of
27 concentrations of cobalt and/or other metals in the metal-working fluid. The required
28 recirculation time depends on the volume of metal-working fluid to be treated, the initial
29 cobalt/metal concentrations to be reduced, the desired cobalt/metal concentrations to
30 be achieved, the flow rate of the metal-working fluid through the filter, and the properties

1 of the particular ion-exchange resin employed. Some experimentation may be required
2 to determine the appropriate recirculation time.

3 **[0047]** The ion-exchange resin preferably comprises polystyrene cross-linked with vinyl
4 benzene which has been functionalized to include multiple sulfonate groups. This resin
5 is readily available commercially, and typically takes the form of granules ranging in size
6 from a few hundred microns to a few millimeters in size. Such resins are typically used
7 in hydrogenated form (acidic) or as sodium salts (neutral or basic). Metal-working fluids
8 are often used around pH 9 or 10, so the sodium form of the resin may be preferred. As
9 metal-working fluid flows through the resin, cobalt or other metals to be removed are
10 bound by the resin, which releases sodium ion in exchange. The capacity of the resin
11 to absorb cobalt and/or other metal ions is therefore finite, and the resin must be
12 periodically replaced. Without departing from inventive concepts disclosed and/or
13 claimed herein, any functionally equivalent ion-exchange resin may be employed.
14 Examples are disclosed in US Pat. Nos. 4,871,779 and 5,545,798, said patents being
15 hereby incorporated by reference as if fully set forth herein. Upper and lower packings
16 330 and 332 may preferably comprise a woven or mesh fiberglass packing material
17 having a weave sufficiently dense to retain the resin granules. The weave or mesh may
18 be regular or irregular. Other materials may be equivalently employed, such as glass
19 wool, cloth or textile weave or mesh, paper-based packing, and so forth.

20 **[0048]** An ion-exchange filter may be used to treat metal-working fluid 150 from holding
21 vessel 200. Fluid may be drawn from holding vessel 200, through the ion-exchange
22 filter, and returned to holding vessel 200. Recirculation of the metal-working fluid from
23 holding vessel 200 may take place before, during, and/or after cooling of the metal-
24 working fluid, although treatment after cooling may be preferred. The appropriate
25 recirculation time may be determined as described hereinabove. An immersion pump
26 may be placed within holding vessel 200 for recirculating metal-working fluid through the
27 ion-exchange filter, an air-flow amplifier may be employed as described hereinabove, or
28 any other functionally equivalent pump may be employed. Alternatively, metal-working
29 fluid from heating vessel 100 may be recirculated through the ion-exchange filter.
30 Alternatively, the ion-exchange filter may be provided as a completely independent
31 component for treating metal-working fluid, and the metal-working fluid may be

1 recirculated through the ion-exchange filter from a sump of a metal-working machine or
2 any other container or vessel.

3 **[0049]** In a preferred application of the present invention, the apparatus may be
4 provided with a rolling base for allowing it to be readily moved around a machine shop.
5 The apparatus may be moved to a metal-working machine with fluid needing treatment,
6 and the filling/heating cycle begun. The apparatus may remain in place and the metal-
7 working fluid returned after treatment to the metal-working machine from whence it
8 came. A more efficient use of the apparatus would have the filling/heating cycle begin
9 with already-treated metal-working fluid in a full holding vessel. After transferring the
10 metal-working fluid (in need of treatment) from the metal-working machine into the
11 heating vessel, the already-treated metal-working fluid may then be transferred to the
12 metal-working machine. The metal-working machine therefore experiences minimal
13 downtime due to treatment of the metal-working fluid. After the metal-working fluid has
14 been treated, the apparatus may transfer metal-working fluid in need of treatment from
15 a metal-working machine (the same machine or a different one) and promptly refill the
16 machine with already-treated metal-working fluid from the holding vessel.

17 **[0050]** All aspects of the apparatus and methods disclosed and/or claimed herein may
18 be under automated control, manual control, or some combination thereof. Level
19 sensors, temperature sensors, pressure sensors, timers, and/or other monitoring gear
20 may be monitored by a computer and/or other processor, and suitable commands
21 generated and transmitted to the valves, pumps, and/or other devices as appropriate for
22 the methods shown and described herein.

23 **[0051]** Methods and apparatus according to the present invention as disclosed and/or
24 claimed herein may be applicable for treating other types of fluid. For example,
25 methods and apparatus according to the present invention may be suitable for treating
26 drinking water and/or other potable liquids. Additional treatment steps may be added,
27 such as ozonation and/or UV irradiation, for example, to provide an enhanced level of
28 treatment.

29 **[0052]** The present invention has been set forth in the forms of its preferred and
30 alternative embodiments. It is nevertheless intended that modifications to the disclosed

- 1 apparatus and methods for treating metal-working fluid may be made without departing
- 2 from inventive concepts disclosed and/or claimed herein.